Oceanic distribution and behavior of green sturgeon (*Acipenser medirostris*)

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Abstract

Pop-off archival tags (PATs) and trawl-logbook data were used to study distribution, movement and behavior of green sturgeon (*Acipenser medirostris*) off the U.S. and Canadian west coasts. Seven green sturgeon were tagged with PATs in the Rogue River, Oregon during the Fall of 2001 and 2002. All fish left the Rogue River and entered the ocean within 32 days of tagging. Six of seven tags popped off and transmitted data to satellites, as planned, 2.5 to 7.7 months after leaving the Rogue River. One tag detached prematurely 5.7 months after tagging, but it drifted ashore near Astoria, Oregon and was returned. All PAT-tagged sturgeon migrated north of the Rogue River within eight months after entering the ocean; pop-off locations ranged from the central Oregon coast to northwest-Vancouver Island, Canada. Estimated distances migrated through nearshore waters ranged from 221 to 968 km. Potential concentration sites off the Oregon and Washington coasts were identified using PAT and Oregon trawl log book data sets. Green sturgeon exhibited a narrow and shallow depth distribution (typically < 100 m) over the continental shelf. This limited-depth distribution makes green sturgeon vulnerable to trawl bycatch in the open ocean, especially if trawling effort within the narrow depth range increases. Although green sturgeon with PATs typically occupied depths of 40-70 m, they also occasionally made what appeared to be rapid-vertical ascents to the surface. Green sturgeon tagged with PATs often were more active and occupied shallower depths during night than during the day. Green sturgeon are harvested by commercial, treaty, and sport fisheries. Because population trends and abundance of green sturgeon are uncertain, and because green sturgeon from the main spawning rivers are likely mixed along the U.S. west coast, conservative management measures should be implemented throughout green sturgeons' range to limit fishing mortality and to ensure effective conservation.

Green sturgeon (*Acipenser medirostris*) is an anadromous species that occurs along the west coast of the USA and Canada from Mexico to the Bering Sea (Moyle 2002). Like other sturgeons, green sturgeon are slow growing and mature late in life (Nakamoto et al. 1995; Farr et al. 2001; Moyle 2002). This species is known to spawn only in the Sacramento and Klamath river systems in California, and in the Rogue River in Oregon (Erickson et al. 2002; Moyle 2002). Erickson et al. (2002) showed that after spawning in the Rogue River, green sturgeon selected specific in-river sites where they remained until late fall to early winter, when they returned to the ocean.

Green sturgeon were petitioned to be listed as threatened or endangered under the U.S. Endangered Species Act (ESA) during 2001 (EPIC 2001). This petition led to the development of a comprehensive status review by Adams et al. (2002). Based on this status review, NOAA Fisheries determined that available information did not warrant listing green sturgeon under the ESA (NARA 2003a). However, information available at the time of the status review was sparse. For example, Adams et al. (2002) were unable to determine the status of green sturgeon because population data were lacking. Almost nothing was known regarding spawning periodicity, stream fidelity, and oceanic-migration patterns for individuals spawning in specific rivers (i.e., Rogue, Klamath, and Sacramento rivers).

It is imperative to understand the distribution and migration patterns to effectively manage green sturgeon throughout its range. For example, green sturgeon are harvested outside of spawning river systems by various fisheries (Adams et al. 2002; Moyle 2002); however, the effect of harvest to specific spawning populations is uncertain due to the lack of information regarding migration patterns and population size. In this paper, we use trawl-catch information to describe oceanic-distribution patterns of green sturgeon in general, and satellite pop-up archival tags to (PATs) to describe oceanic movements and behavior of green sturgeon that spawned in the Rogue River, Oregon.

Methods

Sampling took place in the lower 20 km of the Rogue River, Oregon (Figure 1) during October 2001 and November 2002. Twenty-five green sturgeon and one white sturgeon were caught using sinking monofilament gill nets (23 cm stretched mesh). All specimens were measured (fork and total length) and marked with spaghetti tags (at the base of the dorsal fin). Pectoral-fin clips were removed for genetic analyses. Seven of the green sturgeon were tagged with PATs (Wildlife Computers). These PATs measured 175 mm in length (not including the antennae) and weighed 75 g in air. They were attached to 180 kg (tensile strength) monofilament that was passed through the base of the dorsal fin using a tagging needle. All fish were immediately released following the tagging process.

Because PATs were externally attached, we were unable to determine the sex of tagged fish, except for two individuals that had been captured previously (Specimens 3 and 6; Table 1). Specimen 3 was originally caught in the Rogue River on 10 April 2001, whereas specimen 6 was caught in the river on 15 October 2002. Transmitters were surgically implanted into the abdominal cavity of both fish during the first-capture event using methods described by Erickson et al. (2002). Sex and gonad condition were visually and microscopically assessed for these individuals.

The PATs were programmed to release from green sturgeon 3.5 to eight months following activation (Table 1). Immediately after release, PATs ascended to the ocean surface and began transmitting data (including location) to NOAA satellites. Data were then downloaded to earth by Service Argos. Service Argos subsequently processed transmitted data, estimated positions of the tags during transmission, and emailed data to the authors. Distance between the mouth of the Rogue River and the tag-release location was estimated as the minimum distance through nearshore waters (i.e., following the west-coast contour). Although PATs recorded temperature, depth, and light every minute, transmitted data were summarized as the proportion of time tags spent within user-specified ranges (= cell widths) during 12-hour periods. Ten cell widths were defined for both depth and temperature. Maximum values for depth (m) cells were 0, 5, 10, 20, 30, 40, 50, 75, 100, 125, 150, and 1000, whereas maximum values for temperature (^{o}C) ranges were 2.5, 5, 7.5, 10, 12.5, 15, 17.5, 20, 22.5, 25, 30, and 60.

Four of the seven PATs were recovered, which enabled us to download the complete set of archived data (depths and temperatures for every minute that tags were at large). Transmitted data were analyzed for three PATs that were never recovered (Specimens 4, 5, and 6; Table 1). Mean depths and temperatures were easily calculated for archival data, but additional assumptions were required to estimate mean depths and temperatures for transmitted data. For these cases, mean temperature or depth was calculated as follows for each 12-hour period:

$$\overline{X} = \sum_{i=1}^{10} \left(M_i \bullet P_i \right)$$

where

$\overline{X} =$ Mean temperature or depth for a specific 12-hour period,

M_i = midpoint of each cell (*i*) for a specific 12 hour period, and

P_i = proportion of time spent within each cell (*i*) during a specific 12 hour period.

Overall means were then calculated as the average of the 12-hour averages.

Emigration date from the Rogue River to the ocean was estimated using two methods. The precise date and time of outmigration was known for the two green sturgeon (Specimens 3 and 6) carrying transmitters, because their departure was detected by data-logging receivers at the mouth of the river (see Erickson et al. 2002). We estimated the date and time that the remaining individuals entered the ocean based on depth information provided by PATs. Maximum depth of the Rogue River is typically shallower than 20 m (except for a few locations far up river). Hence, the date and times that depths exceeded 20 m (during the Fall out-migration period; see Erickson et al. 2002) was assumed to be the date and time that green sturgeon entered the ocean.

Trawl-logbook data

Trawl-log book data including date, location (latitude and longitude), depth, and presence/absence of green sturgeon in the catch were obtained from Oregon Department of Fish and Wildlife (ODFW) for the years 1993 – 2000. Only bottom-trawl data for boats that landed catches in Oregon ports were included for these analyses. Data for pink shrimp (*Pandalus jordani*) and mid-water sets were excluded.

We caution that the logbook data should only be used to characterize the spatial distribution of green sturgeon. The actual encounter rate of green sturgeon by trawlers is likely much different than presented here, for several reasons. These data only reflect vessels that landed catches in Oregon ports. Hence, effort and catch data for vessels that delivered in California, Washington, and British Columbia are not shown. In addition, captains visually assessed the catch when completing logbooks, or relied on the crew to estimate the amount of each species or species group that was retained after each haul (during years shown herein); hence, it is likely that only green sturgeon retained for sale were recorded. Bycatch species that were discarded and rare in the catch, such as under- or over-sized sturgeon, were often not recorded in logbooks during this time period (D. Erickson, personal observation). Finally, catch and encounter rates are likely different at present than shown in this manuscript, because regulations and fishing effort have changed dramatically since 2000.

Results

Prior to tagging wild fish, we tested the PAT-attachment procedure using a dummy PAT on white sturgeon (*A. transmontanous*) held at the ODFW Willamette Fish Hatchery in Oakridge, Oregon. The dummy-PAT tag remained attached to the white sturgeon for approximately one year, after which it was removed by ODFW staff. The white sturgeon remained healthy throughout the tagging period (G. Yeager, ODFW, personal communication).

Seven green sturgeon were caught by gill net and tagged with PATs 11.5 to 19.5 km above the mouth of the Rogue River during October 2001 and November 2002 (Table 1). Total lengths (TL) for these individuals ranged from 165 to 215 cm. Two of the green sturgeon tagged with PATs were mature females; the remaining five were not sexed. Green sturgeon carrying PATs left the Rogue River within 32 days of tagging (Table 1).

All PATs released from green sturgeon 2.5 to eight months after leaving the Rogue River (Table 1). Six of seven PATs released from fish as programmed and transmitted data to satellites. One PAT released prematurely (Specimen 3), and therefore, did not transmit data. This PAT was later found on the beach; the reason for premature detachment was a faulty pin provided by the manufacturer (not because of the tagging method). Three other PATs were also recovered (Specimens 1, 2, and 7).

Green sturgeon migrated 221 to 968 km after leaving the Rogue River (Table 1). All PATs released from fish in coastal waters, with the exception of specimen 6, which was inside of Grays Harbor, Washington at the time of tag release (Figure 1). The greatest distance from the Rogue River (968 km) was reached by specimen 4 in less than four months (Table 1). All six fish for which we were able to determine tag-release location migrated northward to locations between central Oregon and northwest Vancouver Island (Figure 1). The PAT that released prematurely (Specimen 3; Table 1) did not transmit location data, but was found 407 km north of the Rogue River only six days after detachment. All PATs released inside of the 110 m depth contour (Figure 1).

Trawl catches of green sturgeon occurred throughout the Oregon and Washington coasts, with concentrations near major coastal ports (e.g., Coos Bay, Newport, and Astoria Oregon), major estuaries (e.g., Grays Harbor and Willapa Bay, Washington), and off the Olympic Peninsula, Washington (Figure 2). Most reported locations of green sturgeon catch by Oregon trawlers were inside of the 110 m depth contour, whereas most bottom-trawling effort was conducted deeper than 110 m (Figure 2).

Average daily depths and temperatures for individual green sturgeon after leaving the Rogue River are shown for PAT-archival data (Specimens 4, 5, and 6; Figure 3) and for data transmitted from PATs to satellites (Specimens 1, 2, 3, and 7; Figure 3). After leaving the Rogue River, all green sturgeon carrying PATs spent most of the time at depths between 40 and 100 m from November through April (Figure 3). The two green sturgeon that retained PATs into June averaged much shallower depths during May and June than during the November through April period (Figure 3). Specimen 6 was inside of Grays Harbor when the PAT detached and began transmitting on 30 June 2002 (Figure 1). Depth data suggests that this fish entered Grays Harbor on 22 May 2002 (Figure 3). Overall, mean depths for green sturgeon ranged from 49 to 69 m (Table 2). Average water temperatures inhabited by green sturgeon after leaving the Rogue River ranged from 10.1 to 10.9 ^{o}C; minimum and maximum values were 7.3 ^{o}C and 12.5 - 15 ^{o}C.

Although PAT-tagged green sturgeon typically were found at depths exceeding 40 m while in the open ocean (Figure 3), they occasionally exhibited dramatic changes in depth (Figure 4). As results for specimen 7 illustrate (Figure 4), minimum depth often approached 0 m even though the mean depth remained fairly constant. All specimens showed minimum depths of 0 to 5 m while in the ocean (Table 2). Ascents to depths $\leq$ 10 m (i.e., to near the surface) from deeper starting depths (mostly > 40 m) typically occurred in only about 3 to 5 minutes (Table 3). Elapsed time for ascents to depths $\leq$ 10 m increased with increasing start depth, ranging from 2 minutes (29 m start depth) to 11 minutes (111 m start depth). Hereafter, we refer to this behavior of rapidly swimming from near bottom to near surface as vertical-surface ascents. The frequency of vertical-surface ranged from a minimum of 5 surface events in 2.5 months (Specimen 1) to 26 surface events in 7.2 months (Specimen 7; Table 3). Vertical-surface ascents occurred 0 to 8 times per month, depending on the individual and the month.

Activity of green sturgeon in the ocean typically was higher at night than during the day (Figure 6). Thirty eight of 45 vertical-surface ascents took place during dusk, dark, and dawn (Table 3). Results for specimen 7 (Figure 6) show greater activity level and shallower swimming depths at night than during the day. Specimens 1, 2, and 3 showed similar diel behaviors.

Discussion

Green sturgeon larger than 152 cm TL are generally considered mature (i.e., spawning adults; Moyle et al. 2002) and are prohibited in the catch for sport fishers (Adams et al. 2002). All green sturgeon tagged with PATs were larger than 152 cm TL (Table 1). Two of the green sturgeon were mature adults (Table 1) that likely spawned in the Rogue River. Specimen 3 was filled with ripe eggs on 10 April 2001 when first captured (Erickson et al. 2001). The gonad of specimen 6, which was caught on 15 October 2002, was classified as a post-spawning ovary based on a histological assessment. The condition of the gonad suggested that this individual had spawned in the Rogue River during recent months (M. Webb, Oregon State University, unpublished data).

Data on gonadal stages suggest that most green sturgeon enter the Rogue River during the spring to spawn (M. Webb, Oregon State University, unpublished data). After spawning, individuals remain in the river throughout the summer and early fall months until flows begin to increase, which is typically November and December for the Rogue River (Erickson et al. 2002). This study was intentionally designed to take place during the Fall, just prior to green sturgeon migration back to the ocean, to minimize the possibility of PAT-tag loss in the river or the capture of tagged green sturgeon by sport fishers. This approach was effective, in that green sturgeon tagged with PATs departed the Rogue River within approximately one month after tagging (Table 1).

Our PAT data suggest a northern migration (at least to 968 km) for green sturgeon during the first eight months after entering the ocean from the Rogue River (Figure 1). Other mark-recapture studies suggest a similar tendency for northward migration after leaving rivers and estuaries. Adams et al. (2002) summarized mark-recapture information from Chadwick (1959), Miller (1972) and unpublished sources to demonstrate a general trend for northward migrations by green sturgeon. They showed thirteen of fifteen green sturgeon tagged in San Francisco Bay were later recovered at more northern locations. Adams et al. (2002) also showed that 23 of 28 green sturgeon tagged in the Columbia River were recaptured at more northern sites.

Clearly, green sturgeon do not only migrate north; individuals also travel south along the Pacific coast of the USA and Canada. Adams et al. (2002) reported that 7 of 43 green sturgeon were recovered south of tagging sites. Recent information verify that some green sturgeon from the Rogue River migrate south to California waters within one year after leaving the river (Washington Department of Fisheries, unpublished data). One individual that was caught and tagged on 27 June 2000 in the Rogue River by a WCS-ODFW collaborative project (see Rien et al. 2000 and Erickson et al. 2002) was reportedly found dead at the mouth of the Klamath River on 7 May 2001 (Washington Department of Fisheries, unpublished data). At the time of capture in the Rogue River, this individual (see Specimen 12 in Erickson et al. 2002) measured 225 cm total length and was full of ripe, green eggs (D. Erickson, unpublished data). This green sturgeon migrated into the ocean from the Rogue River on 6 December 2000 (Erickson et al. 2002). This is the first evidence of green sturgeon movement between the Rogue and Klamath rivers.

Previous studies have indicated that green sturgeon are widely dispersed along the west coast of the USA and Canada (Adams et al. 2002; Beamesderfer and Webb 2002; Moyle 2002). Our results are generally consistent with this pattern; PAT releases demonstrated that green sturgeon from the Rogue River migrated as far north as Vancouver Island, Canada (Figure 1). Our data are suggestive, however, of concentration sites for green sturgeon in coastal waters. This agrees with Edwards et al. (This volume) who found that Gulf sturgeon (*Acipenser oxyrinchus desotoi*) tend to concentrate at specific sites along the Florida coast line. Trawl logbook data revealed areas of concentrated green sturgeon catch (Figure 2). Clearly, trawl logbook data must be interpreted cautiously because catches clustered near major fishing ports (e.g., Coos Bay, Newport, and Astoria, Oregon) may reflect in part the distribution of fishing effort. However, it important to note that three of the four PATs that released in Washington-Oregon coastal waters were released in areas where green sturgeon were also caught by trawl (see Figures 1-2). These areas were off Newport, Oregon, where two PATs were released, and the Olympic Peninsula, Washington.

Our results and mark-recapture results shown by Adams et al. (2002) suggest that northwest-Vancouver Island may represent an important oceanic concentration site for green sturgeon. One PAT (specimen 4) was released in this area, near Quatsino Sound, on 28 February 2003 (Figure 1). Adams et al. (2002) reported that three of 28 recaptured green sturgeon (originally tagged in the Columbia River) also came from this same area in northwest-Vancouver Island. The PAT was released during a herring-roe fishery, leading us to hypothesize that northwest-Vancouver Island may provide important habitat for green sturgeon, possibly as a feeding area. More PAT-tagging work is needed to verify these potential concentration sites, and to identify additional important oceanic habitats for green sturgeon.

Mean depths recorded by PATs should be useful for evaluating whether green sturgeon were offshore or inside of bays (Figure 3). There is little evidence that green sturgeon entered estuaries or rivers (i.e., shallow water < 20 m) during winter and early spring months, with the possible exception of specimen 5, which spent considerable time between 20 and 30 m during January and February (Figure 3). Two green sturgeon carrying PATs into June averaged shallower depths during May and June than during the November through April period, suggesting that green sturgeon tagged with PATs from the Rogue River entered estuaries (or shallow-coastal waters) during early summer months. Indeed, one of these PATs released inside of Grays Harbor on 30 June 2002 (Figure 1). These results support Adams et al. (2002), who reported that green sturgeon tend to concentrate in estuaries during summer months. It is possible that these summer concentration sites consist of green sturgeon from various river systems (Moyle 2002). Miller (1972) showed that one green sturgeon tagged in San Pablo Bay of the Sacramento river system was recaptured in Grays Harbor. Hence, we demonstrate that green sturgeon from both the Rogue and Sacramento river systems have entered Grays Harbor during summer months.

Although green sturgeon latitudinal distribution is broad, their depth distribution in the ocean is narrow. This is similar to findings by Fox et al. (2002) and Edwards et al. (This volume), who showed shallow and narrow depth distributions for Gulf sturgeon. Our data sets demonstrated that green sturgeon were generally found at depths less than 110 m while in the ocean (see Figures 1, 2, and 3). All PATs released at depths less than 110 m (Figure 1), and PAT data show that green sturgeon were typically found between 40 and 70 m during winter and spring months (Figure 3; Table 1). These data are supported by the Oregon trawl logbook data, which demonstrate that green sturgeon are mostly caught inside of 110 m by bottom trawls. Note that some of the locations provided by Oregon-trawl logbooks were likely erroneous (e.g., locations that were excessively deep or on land), however, the overall pattern for green sturgeon catch by trawl appears clear (shallow depths and broad-latitudinal distribution).

Potential Negative Effects of Depth-Based No-Trawl Zones

Based on Oregon trawl logbook data, most trawling effort during 2000 was outside of 110 m, whereas most green sturgeon bycatch was inside of this depth contour (Figure 2). This suggests that green sturgeon bycatch may increase if trawling effort increases in shallow waters. Although recent fishing regulations have reduced trawling effort overall through a vessel-reduction program along the U.S. West coast (NARA 2003b), it is possible that trawling effort for U.S. vessels could increase inside of 110 m because of a recently created no-trawl zone (Rockfish Conservation Area, RCA) that extends from the Mexican to the Canadian border (NMFS 2004). This depth-based management, first implemented in 2002 to protect a complex of shelf rockfish (*Sebastes*) species that have been overfished, now prohibits trawling between 110 and 336 m off the Washington, Oregon, and northern California coasts (NMFS 2004). Trawling effort has historically been high within the 110 – 336 m depth range that is now protected by the RCA (Figure 2). It is plausible to assume that some of the effort that was employed within the RCA prior to 2002 (Figure 2) will shift to shallower waters (i.e., inside of 110 m), particularly during the winter season when storms are frequent. This may increase mortality for green sturgeon, as well as other species, that exhibit a narrow and shallow depth distribution.

Behavior

We found that green sturgeon typically exhibited greater activity and swam at shallower depths during the night than during the day (Figure 5). This increased diel activity included occasional rapid ascents to the surface (Table 3). Other species exhibit diel swimming patterns that include changes in swimming depth and differences in activity levels. Vertical migrations and increased activity may occur at night in response to vertically migrating prey (West and Stevens 2001), during the day to provide some minimal light threshold needed to visually detect prey (Nichol and Somerton 2002), or during the day for sun-assisted orientation during open ocean migration (Kitigawa et al. 2002). It is likely that green sturgeon are more active at night as a response to food availability.

The vertical migrations shown for green sturgeon were likely rapid-vertical ascents to the surface, rather than inshore migrations (i.e., following the bottom contour to shallow water). Given the rate of depth change, and that PATs recorded depth only once per minute, the actual minimum depth would be measured with considerable error. Hence, we made the assumption that depths greater than 20 m were routinely occupied, and depths within 10 m of the surface represent vertical-“surface” ascents while in the open ocean.

Green sturgeon have been observed breaching the surface in river systems (D. Erickson, personal observation). Jumping behavior has been documented for other species of sturgeon while in freshwater (Sulak et al. 2002). However, our data and observations by Edwards et al. (This volume) may be the first published evidence of vertical ascents to the surface by sturgeons while in the open ocean. The purpose of this behavior is unknown (Sulak et al. 2002). Some suggested reasons for jumping behavior by fish include to shed parasites, to escape predators, a startle-fright response, to gulp or expel air, to defend territory, to exercise, random activity, or even as a means of group communication (Sulak et al. 2002).

Conclusion

Athough it is currently thought that green sturgeon spawn in only three river systems (Adams et al. 2002; Moyle 2002), there is little known about the extent of mixing (or separation) for green sturgeon originating from these systems. This information is imperative for stock assessments, management, and conservation of this species. For example, are Rogue River and Klamath River green sturgeon exposed to same or different threats? Do fish from these spawning rivers “mix” in the ocean, estuaries, and rivers? Although it has been assumed that green sturgeon originating from different river systems (e.g., Sacramento, Klamath, and Rogue) are likely mixed while in the open ocean (i.e., most show northerly migrations), we report direct evidence of mixing (green sturgeon tagged in the Rogue River and migrating into the Klamath River). Our PAT and trawl logbook results also lend support to the idea of concentration areas for green sturgeon in certain regions of the coast and in estuaries (e.g., Grays Harbor, see above). Management measures designed to protect one spawning stock (e.g., green sturgeon that spawn in the Rogue River) should encompass the full geographical range of the species, particularly those regions where green sturgeon appear to concentrate.

Green sturgeon are harvested by treaty gillnet (i.e., Klamath River, Willapa Bay, and Grays Harbor), commercial gillnet (i.e., Columbia River, Willapa Bay, and Grays Harbor), bottom trawl (i.e., Oregon and Washington coasts), and sport anglers in various estuaries and rivers (Adams et al. 2002). Results of this and other tagging studies regarding the apparent mixing of green sturgeon from the three major spawning-river systems, suggest that conservative management measures should be implemented to ensure the conservation and survival of green sturgeon from all three spawning systems. It will also be important to assess the impact of the recently implemented no-trawl zone (i.e., RCA) on green sturgeon, given their nearshore distribution.

The PAT and archival tags used in this study were effective for documenting the direction of migration, depths occupied, and some aspects of behavior. The main limiting factor in describing migration and identifying concentration areas along the U. S. west coast is in obtaining an adequate sample size. Along with conventional tagging and recapture of tagged individuals in fisheries and surveys, the PAT tagging studies are essential for determining habitat preferences and the extent of mixing by green sturgeon from the three major spawning systems.

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Table 1. Data for green sturgeon that were caught by gillnet and tagged with satellite pop-off archival tags in the Rogue River, Oregon during 2001 and 2002. Departure date is the date that each individual entered the ocean. Distance traveled is the estimated minimum distance through nearshore waters between the mouth of the Rogue River and the tag-release location.

Specimen	Tagging date	Total length (cm)	Sex	Departure date	Intended tag-release date	Actual tag-release date	Distance traveled (km)
1	10/16/01	210	U	11/17/01	1/31/02	1/31/02	354
2	10/16/01	207	U	11/16/01	3/30/02	3/30/02	231
3	10/16/01	215	F	11/15/01	6/30/02	4/6/02	Unknown
4	11/05/02	166	U	11/11/02	2/28/03	2/28/03	968
5	11/05/02	183	U	11/16/02	4/30/03	4/30/03	221
6	11/05/02	176	F	11/10/02	6/30/03	6/30/03	508
7	11/05/02	165	U	11/25/02	6/30/03	6/30/03	636

Table 2. Depths and temperatures occupied by green sturgeon while in the ocean beginning eight days after departure from the Rogue River, Oregon. Data shown for fish 1-3 and fish 7 reflect archival data, whereas those shown for the remaining fish represent transmitted data.

	Depth (m)			Temperature (^{o}C)		
Specimen	Min	Max	Mean	Min	Max	Mean
1	0	117	56.2	8.5	12.1	10.9
2	2	93	49.9	8.5	12.1	10.4
3	0	111	58.0	7.6	11.9	10.1
4	0-5	> 150	67.3	7.5 – 10	12.5 – 15	10.1
5	0-5	> 150	49.0	7.5 – 10	12.5 - 15	10.6
6	0-5	75-100	69.2	10 – 12.5	12.5 – 15	10.6
7	1	117	66.7	7.3	13.5	10.6

Table 3. Summary of vertical ascents to the surface by green sturgeon tagged with PATs. Vertical-surface ascents are shown during day, dusk, night, and dawn hours. An ascent to the surface was defined as ascents beginning at depths > 20 m and reaching depths $\leq$ 10 m. The average depth at the start of ascents is shown, as well as the average time required to reach minimum depth. Standard deviations are shown in parentheses.

	Specimen				
Variable	1	2	3	4	Total
Surface ascents during the day	0	0	0	7	7
Surface ascents during dusk	0	0	1	4	5
Surface ascents during night	5	6	7	14	32
Surface ascents during dawn	0	0	0	1	1
Beginning depth (m)	56.5	63.3	51.9	58.8	57.9
	(7.4)	(6.9)	(18.3)	(20.8)	(17.9)
Time to surface (minutes)	3.2	5.0	3.8	4.4	4.2
	(0.8)	(0.8)	(1.0)	(1.9)	(1.6)

Figure Legends

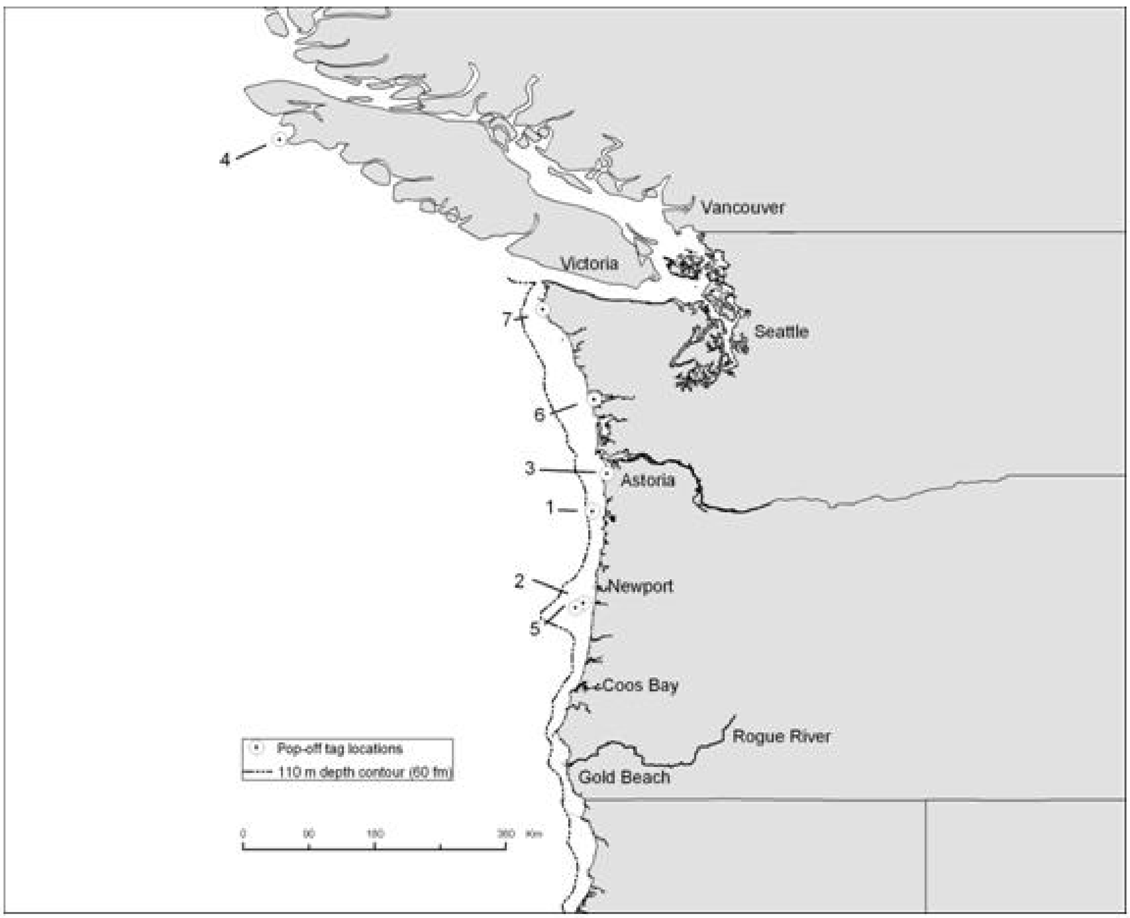
Figure 1. Green sturgeon tagging site (Rogue River, Oregon) and locations of pop-off archival tags (PATs) after detachment from green sturgeon along the coasts of Oregon, Washington and British Columbia. The location of the PAT for specimen 3 is based on where the tag was recovered along the shore, after it detached prematurely.

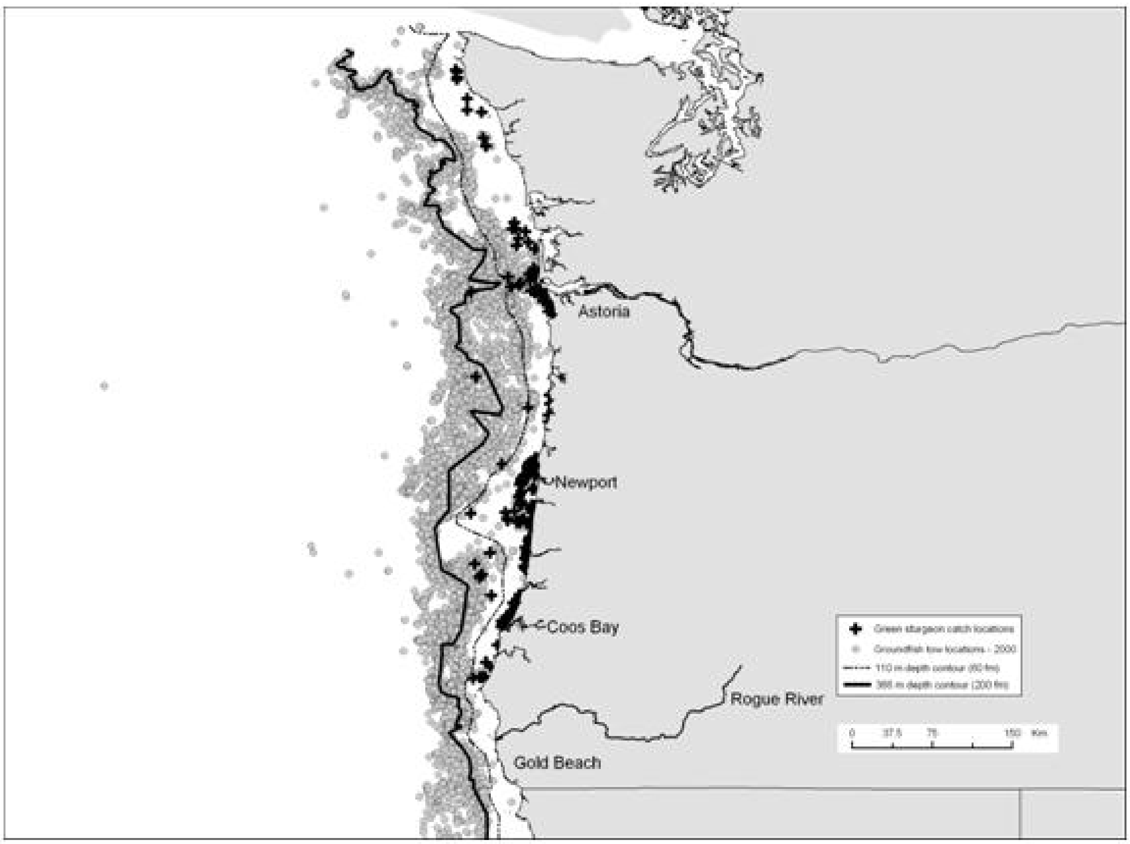
Figure 2. Locations of bottom-trawl sets made during 2000 (circles) and bottom-trawl sets that caught green sturgeon during 1993 - 2000 (crosses) along the Oregon and Washington coasts. Depth contours (109 and 366 m) represent boundaries of a no-trawl zone (= Rockfish Conservation Area) that was implemented after 2000.

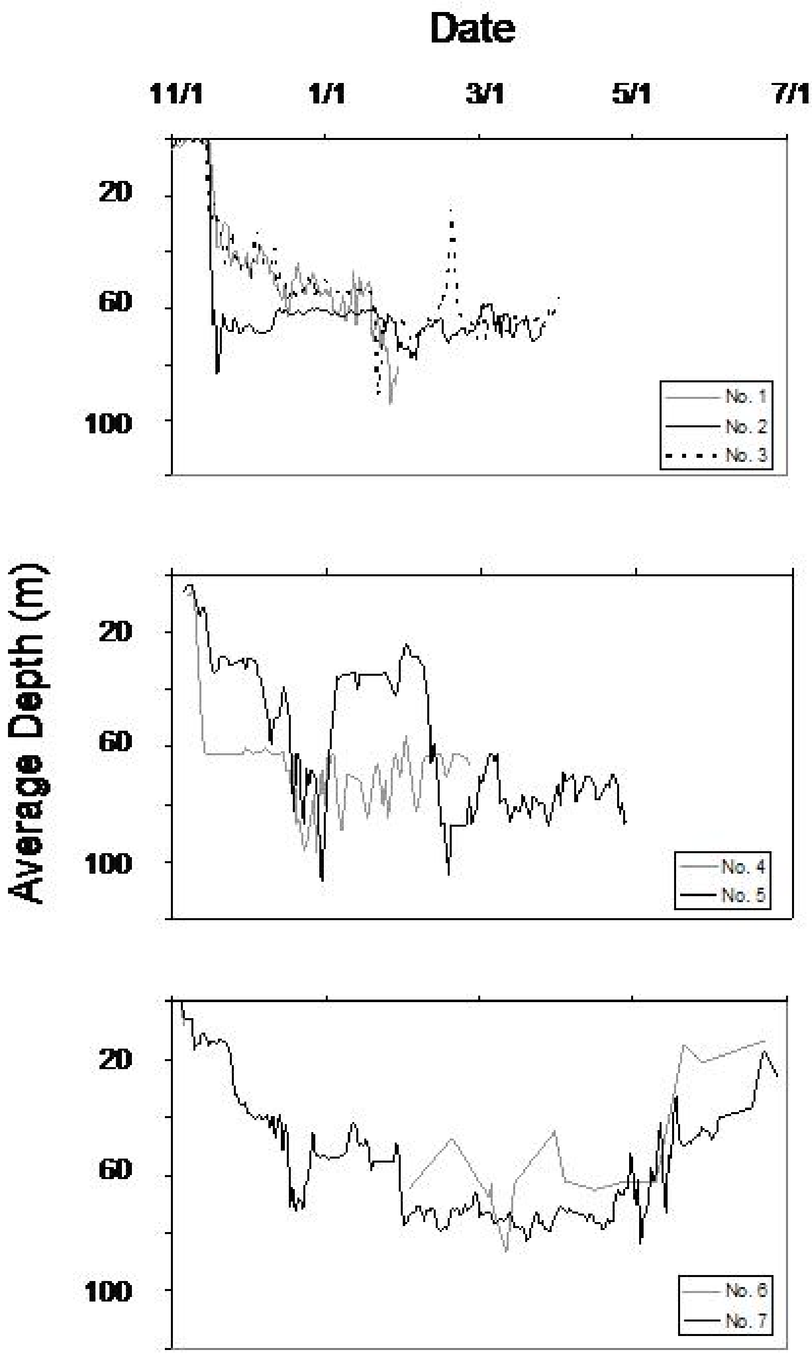
Figure 3. Average daily depth calculated for green sturgeon carrying PATs. Green sturgeon were tagged in the Rogue River, Oregon during late October and early November. Fish entered the ocean during November. Average depths were calculated from archived data (Specimens 1, 2, 3 and 7) and transmitted data (Specimens 4, 5, and 6).

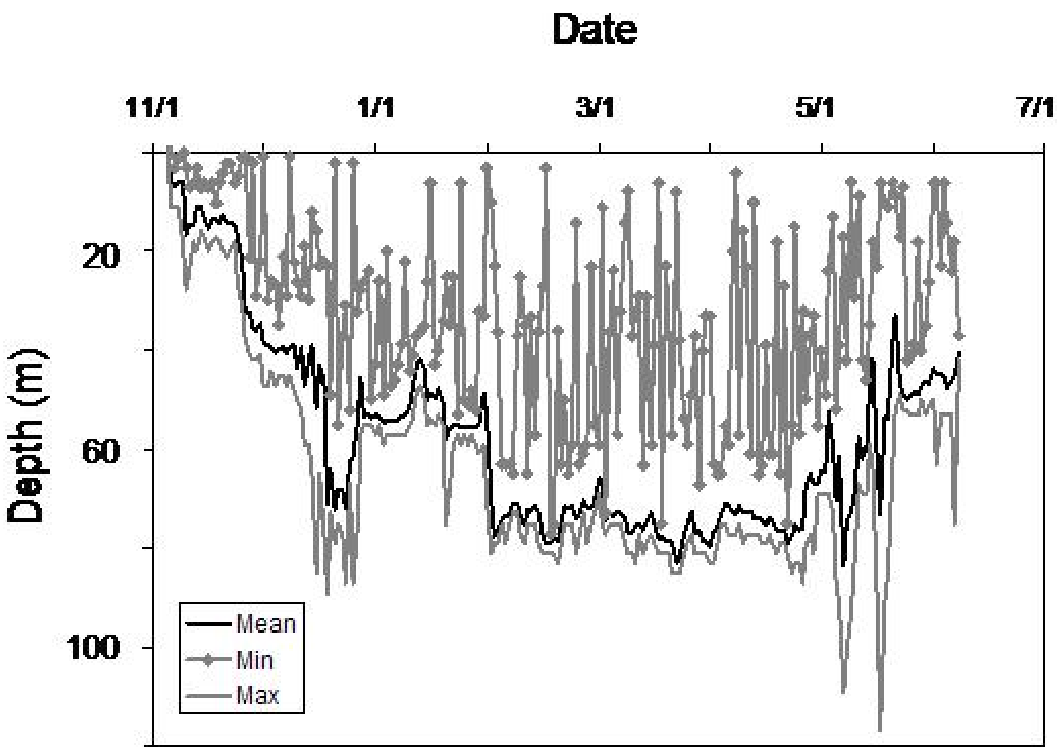
Figure 4. Daily depths (average, minimum, and maximum) for a green sturgeon after entering the ocean. This fish (specimen 7) was tagged in the Rogue River, Oregon with a PAT on 5 November 2002.

Figure 5. Depth (black) and light level (gray) recorded by a PAT attached to a green sturgeon (Specimen 7) while in the ocean during April 2003. Data were recorded every minute.

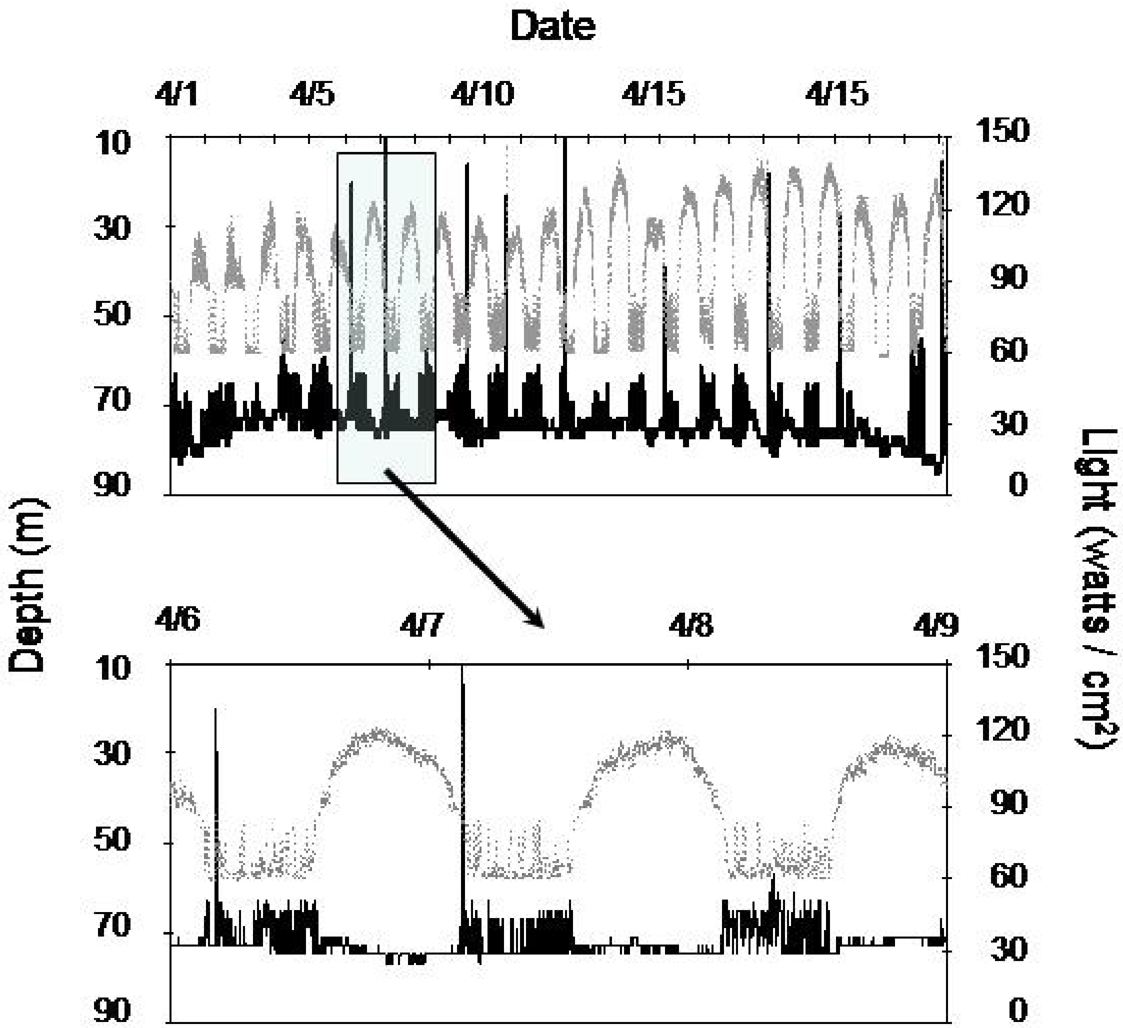

4
Vancouver
Victoria
7
Seattle
6
3
Astoria
1
2
Newport
5
Coos Bay
Rogue River
Gold Beach
Pop-off tag locations
110 m depth contour (60 fm)


Astoria
Newport
Coos Bay
Rogue River
Gold Beach


Date
11/1
1/1
3/1
5/1
7/1
Average Depth (m)
20
60
100
No. 1
No. 2
No. 3
No. 4
No. 5
No. 6
No. 7



1


Date
4/1
4/5
4/10
4/15
4/15
10
30
50
70
90
150
120
90
60
30
0
Depth (m)
Light (watts / cm²)
4/6
4/7
4/8
4/9
10
30
50
70
90
150
120
90
60
30
0